ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia 115 (2017) 50–58
Energy Procedia
www.elsevier.com/locate/procedia

International Conference – Alternative and Renewable Energy Quest, AREQ 2017, 1-3 February 2017, Spain

A New Sustainability Assessment Approach Based on Stakeholder's Satisfaction for Building Façades

Golshid Gilani[*a],Ana Blanco[b],Albert de la Fuente[b]

[a]*Institute of sustainability, Universitat Politècnica de Catalunya (UPC), Jordi Girona 1-3, 08034 Barcelona, Spain*
[b]*Department of Civil and Environmental Engineering, Universitat Politècnica de Catalunya (UPC), Jordi Girona 1-3, 08034 Barcelona, Spain*

Abstract

This paper presents a new Multi-Criteria Decision Making model based on the MIVES method for global sustainability assessment of façade systems. Since 1990, various methods have been proposed for the sustainability assessment of buildings. However, most of the existing methods mainly concentrate on environmental and economic aspects, disregarding the third pillar of sustainability, which is the social aspect. Besides, there is a little focus on comprehensive sustainability assessment of facades, as an important element of a building. This confirms the need of developing new methods for assessing the sustainable performance of building façades as an important step in achieving building sustainability.

Peer-review under responsibility of the organizing committee of AREQ 2017.

Keywords: *Façade, MCDM, MIVES, Sustainability*

1. Introduction

The concept of sustainable development was introduced by Brundtland Commission in 1987. It is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"[1]. After that, various authors defined this concept from different perspective in theory and practice[2, 3]. According to Zavadska and Antucheviciene, sustainable development is "a set of indicators in the multi criteria analysis to include environmental, social and economic aspects of sustainability". In all definitions, environmental, social and economic factors exist as important factors for achieving sustainable development concept[4].

* Corresponding Author: Tel.: +346-7599-5932
Email Address: g.gilani2015@gmail.com

1876-6102 © 2017 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the organizing committee of AREQ 2017.
10.1016/j.egypro.2017.05.006

Now it is being used for various purposes in the society by professional such as construction industry. Sustainable construction is considered as a way to contribute to sustainable development by protecting the environment [5, 6]

Todays, much effort has been made to achieve sustainable buildings through passive building design, building energy regulations, building performance assessment method development [7]. Currently, various building performance assessment methods are being launched to measure building sustainability. Among them is BREEAM, which was developed in 1990 for UK building and construction industry. This was the pioneer of all other building performance assessment methods developed by countries till today and the most widely recognized method for sustainable design rating and sustainability assessment [8, 9]. Since then, various building performance assessment methods have been established all across the world such as High Environmental Quality (HQE) in 1996; Leadership in Energy and Environmental design (LEED) in 2000; CASBEE (Japan) in 2001; Green Globe (Canada) and Green Star (Australia) in 2002, LEED (India) 2005; GBC (Poland) and LEED (Emirates) in 2006; Green Star (South Africa) in 2007; BREEAM (Netherlands) and LEED (Brazil) in 2008 [9].

However, studies have shown that most of the existing assessment methods do not consider important sustainability aspects such as economic, social and comfort, thus leading to non-comprehensive sustainability assessment of buildings [8, 10-12].

Besides, while many studies report on building sustainability assessment [9, 13, 14], research on the potential and sustainable performance of building elements such as building envelope and Façades, as one of the most important fragments of a building envelope, is scarce.

This indicates the need to develop a new comprehensive and integrated approach that can assess the sustainable performance of building facades for achieving building sustainability. In this respect, this paper aims at presenting a new model for assessing the global sustainability of façade systems. For that purpose, the Integrated Value Model for Sustainable Assessment (MIVES) was used as an assessment tool.

2. Literature review

Manioglu and Yilmaz [15] indicated that building envelopes as a barrier between the interior of building and the external environment can decrease the level of mechanical energy needed in building. Building envelopes can protect the interior space from unpleasant external and internal impacts such as pollution, climate change, temperature, humidity, HVAC load, lighting load, etc. Furthermore, building envelopes control solar and thermal flows, as well as moisture flow in and out of the building. It also controls the indoor air quality, fire, wind, rain and acoustic effects on building [7].

The abovementioned reveals the relevance of façades and their role in the sustainability of the building. In spite of importance of this issue, only a few researches have been conducted on sustainability assessment of façade systems with considering all 3 pillars of sustainability; environmental, economic and social.

Previous studies about sustainability assessment of façade and building envelope are listed in Table1.

Table1. Studies on sustainability assessment of façades and building envelopes

Authors	**Year**	**Environmental sustainability assessment**	**Social sustainability assessment**	**Economical sustainability assessment**
Orondo and bedoyo[16]	2012	×		
Iwaro, et al.[7]	2011	×	×	×
Iva Kovacic,et.al[17]	2015	×		×
Zavadskas et al.[18]	2008	×	×	×
Manioglu & Yılmaz[15]	2006			×
R. Emmanuel[19]	2004	×		×
Jinghua Yu, et al.[20]	2009	×		
Šaparauskas, et al. [21]	2010	×	×	×
Bouchlaghem[22]	2000	×		
Perini and Rosasco[23]	2013			×

Yun, et al.[24]	2007	×		
Xing Su & Xu Zhang[25]	2010	×		
Waltenberger[26]	2011	×		×

According to Table 1, the previous studies focused mostly on developing new methods for assessing environmental or economic sustainability of façades. In addition, a few studies proposed new methods for assessing both environmental and economic sustainability of facades. For example, Waltenberger [26] developed a new Tool which is called EEFA for Economic and Environmental life cycle analysis of Façade systems. EEFA is the combination of LCC and LCA for analysis of economic and environmental impacts of various façade systems for the stages production, operation and demolition along the life cycle. Then, Kovacic et al.[17] employed this method to evaluate the three façade-systems. Hauglustaine and Azar [27] utilized a genetic algorithm with around 10 criteria related with code compliance, energy consumption, and costs for the building envelopes optimization.

Among the conducted research on sustainability assessment of facades, only a few authors proposed holistic models for assessing 3 pillars of sustainability in facades. Zavadskas et al.[18] proposed as a method of multiple criteria COmplex PRoportional ASsessment of alternatives with Grey relations (COPRAS-G). In this model parameters of the alternatives are determined by the grey relational grade and are expressed in intervals. Value function in this model is based on the significance of attributes. The IPM (The Integrated Performance Model) is another model which was developed by Iwaro and Mwasha for sustainable performance assessment of residential building envelope. The IPM's framework combined four frameworks such as Life Cycle Cost (LCC), Life Cycle Assessment (LCA), Life Cycle Energy Analysis (LCEA) and Multi Criteria Analysis (MCA). On the other hand, 6 major sustainable performance criteria and 64 sub-criteria identified for sustainability assessment of facades. The criteria used in IPM model for sustainability assessment of facades are more complete than the other one[7].

The model used in this paper is based on MIVES methodology which allows sustainability evaluation and decision-making in multi-criteria processes. The difference between this model and other MCDM models is that MIVES incorporates value function and satisfaction concepts[28]. While in IPM model the value function is based on performance efficiency value and in COPRAS-G is based on significance of attributes. In fact, the use of value functions in the analysis with MIVES allows researchers to transform the results obtained by each indicator, which might have different measurement units, to a non-dimensional magnitude value. This magnitude is intended to indirectly measure the satisfaction grade of the stakeholders.

3. Sustainability assessment model for facades

The model used in this paper is based on MIVES methodology [29, 30]. Since the early 2000s, various research groups have been working on this model and developed the Integrated Value Model for Sustainable Assessment (MIVES). Therefore, MIVES is a Multi- Criteria Decision Making (MCDM) tool that makes it possible to assess three pillars of sustainability (economic, environmental and social) and includes the concept of value functions. It has already been presented to the scientific community and applied to make assessments and decisions in different fields. Application of MIVES in different areas will be explained briefly in the following table.

Table 2. Studies where MIVES methodology was applied

Area of study	**Year**	**Reference**
the choice of the optimal tunnel diameter for the L9 line of the Barcelona subway system	2008	Ormazabal et al.[31]
Sustainability assessment of alternatives for the production of concrete columns	2013	Pons, de la Fuente[32]
assessing sustainability in the construction industry based on occupational health and safety criteria	2014	Reyes et al.[33]
evaluate the most sustainable design to	2012	Pons , Aguado[34]

build schools in Catalonia		
present the EHE model for assessing the sustainability of concrete structures	2012	Aguado *et al.[35]*
developing the probabilistic method MIVES–EHEm–Mcarlo, to give the likelihood of reaching the sustainable objective during the project phase	2012	del Caño et al.[36]
Sustainability assessment of concrete flooring systems	2011	Ballester &Yepes[37]
assessing the sustainability of post-disaster temporary housing units technologies	2016	Hosseini et al.[38]
Assessing the environmental impact of industrial buildings	2010	Lombera , Aprea[30]
Assessing the global sustainability index scores of existing wind-turbine support systems	2015	de la Fuente et al.[39]
assessing the sustainability of concrete and plastic sewerage pipes	2016	de la Fuente et al.[40]
Evaluation of three types of pervious pavements to select the best alternative.	2014	Jato-Espino et al.[41]
optimizing the sustainability of using energy sub-system (shell-and-tube heat exchanger)	2015	Caño et al.[42]
assessing the sustainability of different types of power plants	2015	Barros et al.[43]
Sustainability assessment of concrete flooring systems	2011	Ballester&Yepes[37]
Sustainable site location of post-disaster temporary housing	2016	Hosseini et al.[44]

The MIVES method comprises the phases shown in Fig. 1. Before using the proposed model to assess sustainability performance of facades, it is necessary to define a requirements tree and assign relative weights to each assessment parameter. The requirements tree (stage 2 of MIVES) is a hierarchical diagram in which the various characteristics of the product or processes to be evaluated are defined in an organized manner, normally at three levels: requirements, criteria, and indicators [35].The tree must have a minimum number of indicators, which must be representative and independent of each other, to ensure that, together with the assigned weights, it offers a reliable assessment scenario.

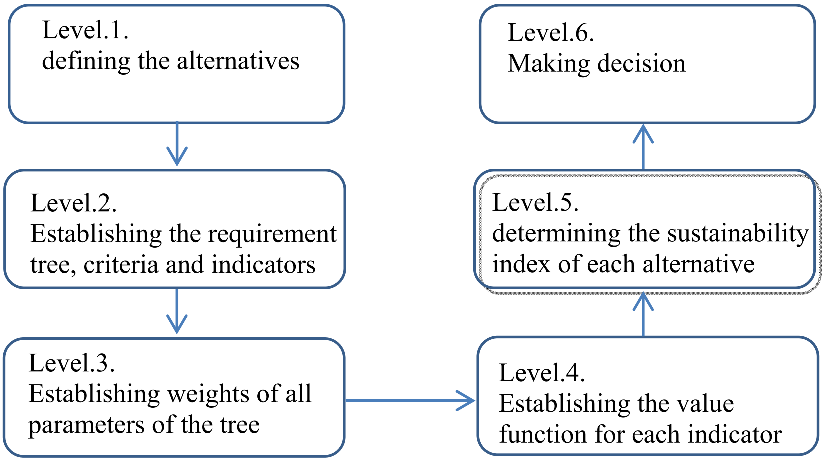

Fig.1. different levels of MIVES for sustainability assessment of facades

Table 3 shows the requirement tree defined based on the previous studies about sustainability assessment of facades and seminars were held with experts in each of the specific subjects related to the field of building envelope. The criteria and indicators mentioned in the tree for sustainability assessment of facades are comprehensive and applicable for any countries. Although, as different locations have different standards and requirements some indicators can be eliminated or changed based on the local characteristics.

Table.3. Requirements Tree

Requirement	**Criteria**	**Indicators**	**Sub indicators**
R_1.Environment	C_1.Consumption	I_1.Energy consumption	
		I_2.Water consumption	
		I_3.Raw material	
	C_2.Waste	I_4.Total solid wastes	
	C_3.Reusability	I_5.Reusability potential	
	C_4.Emission	I_6.CO_2 emission	
R_2.Economic	C_5.Construction	I_7.Material cost	
		I_8.Installation cost	
	C_6.Maintenance	I_9.Maintenance cost	
	C_7.End of life	I_{10}.Dismantling cost	
R_3.Social	C_8.Safety	I_{11}.Safety during construction	
		I_{12}.Safety during service	
	C_9.Comfort	I_{13}.Temperature transfer	
		I_{14}.Noise transfer	
		I_{15}.users flexibility	S_1. visual comfort
			S_2. orientation
			S3. ventilation
			S_4. User control
	C_{10}.Aesthetics	I_{16}.Visual quality	
		I_{17}.Adaptability	
		I_{18}. flexibility	
	C_{11}.added value	I_{19}.local materials	
		I_{20}.traditional architectural strategies	

In this paper, the tree includes three main sustainability requirements which are divided into a total of 20 indicators. The environmental requirement (R1) assesses the environmental effect of facades on the entire life cycle. The economic requirement (R2) takes into account the economic impact of façade, both direct and indirect, over their entire life cycle. The social requirement (R3) is used to assess the impact of each alternative on the society.

After defining the requirements tree, weights should be assigned to all the parameters in the tree. The weightings of the tree's components are also defined at seminars, using the analytic hierarchy process (AHP) [45] and/or direct assignment.

Then, value functions (satisfaction level) have to be defined for each indicator to homogenize the indicators units. In this way all indicators have one single unit normally between 0 and 1. These are values that represent the minimum and maximum degree of satisfaction of each indicator in terms of sustainability [35].

Value function depends on 5 parameters that enable the determination of their shape and thus sensitivity to variations in the indicator's value.

According to Alarcon et al.[46], when satisfaction increases rapidly or decreases slightly, a concave-shaped function is the most suitable. The convex function is used when the satisfaction tendency is contrary to the concave curve case. If satisfaction increases/decreases steadily, a linear function is presented. An S-shaped function is used when the satisfaction tendency contains a combination of concave and convex functions, as shown in Fig. 5.

The parameters, tendency and shape of the value function for each indicator are determined from international guidelines, scientific literature, Iranian National Building Regulations, and the background of experts participated in the seminars.

In the next step, MIVES uses Eq (1) for defining the value function.

$$V_i = A + B \cdot [1 - e^{-ki \cdot (|Xind - Xmin|/Ci)Pi}] \quad (1)$$

A is the response value Xmin (indicator′s abscissa), generally A = 0. Xind is the assessed indicator abscissa which generates a value Vi. Pi is a shape factor that defines if the curve is concave, convex, linear or shaped as a ′′S′′. Ci establishes, in curves with Pi > 1, abscissa′s value for the inflexion point. Ki defines the response value to Ci. B is the factor that keeps the function in the range (0.00, 1.00), the value 1 being that corresponding to the maximum satisfaction. B is defined in the following equation

$$B = [1 - e^{-ki \cdot (|Xind - Xmin|/Ci)Pi}] \quad (2)$$

After the assessment of the sustainability value of the indicators for each alternative technology, in the final stage, the formula that is presented in Eq. (3) should be applied to each tree level. In this equation, the indicator value (Vi(xi)) has previously been determined and the weights (λi) are assigned to determine the sustainability value of each branch. For the multi-criteria case, the additive formula corresponding to Eq. (3) is applied to determine the sustainability value of each facade.

$$V = \Sigma\, \lambda i \cdot Vi\,(xi) \quad (3)$$

Vi(xi), the value function of each indicator and each criterion; λ_i, the weight of considered indicator or criterion.

4. Case study

In order to demonstrate the capability of the MIVES to assess and rank the sustainability of façade alternatives, 3D sandwich panels as a façade-system has been selected as the case study to evaluate the 'Environmental Sustainability Index' of the case study based on the MIVES model. The following data have been obtained from a research which was carried out by Hosseini et al.in 2016[38].

The main characteristics of the 3D sandwich panels are presented in table 4.

Table.4. main features of 3D sandwich panel

Façade technology	Components characteristics	Thermal resistance $(m^2\ k)/w$	Fire resistance	STC	Ductility	Construction time	References

		(h)					
3D sandwich panels	EPS (5cm) Steel mesh (0.25/0.25/8/8) Sprayed concrete(3cm) Sprayed concrete(3cm)	R11 1.9373	1.5	40	Medium to high	High	Charleson, 2008[47] Poluraju & Rao, 2014[48] Sarcia, 2004[49]

In the first phase the requirement tree and assigned weights to each parameter have to be established which are presented in table.5.

Table.5. Requirements tree with assigned weights.

Requirement	Criteria	Indicators
R_1.Environment (30%)	C_1.Consumption (67%)	I_1.Energy consumption (47%)
		I_2.Water consumption (18%)
		I_3.waste material (35%)
	C_4.Emission (33%)	I_6.CO_2 emission (100%)

In the second stage, the value function has to be defined. Regarding the shape of the value functions assigned to the indicators, all four indicators decrease in a convex manner (DCx). Furthermore, the X_{min} and X_{max} of each indicator are defined, as shown in Table 6.

Table.6. Parameters and coefficients for each indicator value function.

Indicator	unit	x_{min}	x_{max}	c	k	p	shape	reference
I1	MJ	2.5×10^2	1.2×10^2	0.2×10^3	0.8	1.6	DCx	Hammond & Jones, 2011[50]
I2	KG	2.15×10^3	2.4 × 102	2.1 × 103	0.2	1.6	DCx	Wuppertal institute for climate[51]
I3	%	20	5	30	0.6	2	DCx	Harris, 1999[52]
I4	kg CO2	26	13	25	0.3	1.4	DCx	Hammond & Jones, 2011[50]

Then, the value function for each of the 4 indicators has been calculated and present in table 7. At the end, the environmental sustainability index of the case study has been defined according to Eq (3) and presented in table 7.

Table.7. environmental Sustainability index (I), requirements (V_{Rk}), criteria (V_{Ck}) and indicator (V_{Ik}), values of the case study

	I	V_{R1}	V_{c1}	V_{c2}	V_{I1}	V_{12}	V_{13}	V_{I4}
3D sandwich panel	0.36	0.46	0.43	0.52	0.33	0.66	0.44	0.52

According to the results, environmental sustainability index of the case study is 0.36 and this procedure can be utilized for calculating economic and social sustainability index of the case study as well. It is possible to compare each aspects of sustainability with each other to consider the strengths and weaknesses of this technology (3d Sandwich Panel).

It can be also used to evaluate the sustainability index of various alternatives and compare them with each other to determine the most sustainable ones.

5. Conclusions

This paper introduced a new model for global sustainability assessment of façade systems. The model is based on MIVES methodology; a multi-criteria decision making tool that enables decision makers to select the most preferable alternatives in terms of sustainability. In order to demonstrate the applicability of the MIVES, environmental sustainability index of 3d sandwich panels, as a case study, was assessed. The same process can be also applied for evaluating social and economic sustainability index of the case study as well. So, this model can be utilized to predict the overall sustainability of various types of façade systems in any location with different characteristics. To this end, some indicators and weights should be adjusted to the new location's characteristics and requirements. However, further verifications need to be conducted to ensure that this model is effective in assessing the global sustainability of façade systems.

References

[1] Butlin, J., *Our common future. By World commission on environment and development.(London, Oxford University Press, 1987, pp. 383£ 5.95.)*. 1989, Wiley Online Library.
[2] Dasgupta, P., *Measuring sustainable development: theory and application.* Asian Development Review, 2007. **24**(1): p. 1.
[3] Sobotka, A. and Z. Rolak, *Multi-attribute analysis for the eco-energetic assessment of the building life cycle.* Technological and Economic Development of Economy, 2009(4): p. 593-611.
[4] Zavadskas, E.K. and J. Antucheviciene, *Development of an indicator model and ranking of sustainable revitalization alternatives of derelict property: a Lithuanian case study.* Sustainable Development, 2006. **14**(5): p. 287-299.
[5] Hill, R.C. and P.A. Bowen, *Sustainable construction: principles and a framework for attainment.* Construction Management & Economics, 1997. **15**(3): p. 223-239.
[6] Ofori, G., et al., *Impact of ISO 14000 on construction enterprises in Singapore.* Construction Management & Economics, 2000. **18**(8): p. 935-947.
[7] Mwasha, A., R.G. Williams, and J. Iwaro, *Modeling the performance of residential building envelope: The role of sustainable energy performance indicators.* Energy and buildings, 2011. **43**(9): p. 2108-2117.
[8] Ding, G.K., *Sustainable construction—The role of environmental assessment tools.* Journal of environmental management, 2008. **86**(3): p. 451-464.
[9] Reed, R., et al., *International comparison of sustainable rating tools.* Journal of Sustainable Real Estate, 2009. **1**(1): p. 1-22.
[10]Soebarto, V. and T. Williamson, *Multi-criteria assessment of building performance: theory and implementation.* Building and Environment, 2001. **36**(6): p. 681-690.
[11]Ding, G.K.C., *The development of a multi-criteria approach for the measurement of sustainable performance for built projects and facilities*. 2004.
[12]Sinou, M., et al., *Present and future of building performance assessment tools.* Management of Environmental Quality: An International Journal, 2006. **17**(5): p. 570-586.
[13]Segnestam, L., et al., *Indicators of environment and sustainable development: theories and practical experience*. 2003: World Bank, Washington, DC (EUA).
[14]Myers, G., R. Reed, and J. Robinson, *Sustainable property–the future of the New Zealand Market.* Pacific Rim Property Research Journal, 2008. **14**(3): p. 298-321.
[15]Manioğlu, G. and Z. Yılmaz, *Economic evaluation of the building envelope and operation period of heating system in terms of thermal comfort.* Energy and Buildings, 2006. **38**(3): p. 266-272.
[16]Orondo, J. and C. Bedoya. *Sustainability Assessment Tool for Façade Cladding*. in *Advanced Materials Research*. 2012. Trans Tech Publ.
[17]Kovacic, I., L. Waltenbereger, and G. Gourlis, *Tool for life cycle analysis of facade-systems for industrial buildings.* Journal of Cleaner Production, 2016. **130**: p. 260-272.
[18]Zavadskas, E.K., et al., *Selection of the effective dwelling house walls by applying attributes values determined at intervals.* Journal of Civil Engineering and Management, 2008. **14**(2): p. 85-93.
[19]Emmanuel, R., *Estimating the environmental suitability of wall materials: preliminary results from Sri Lanka.* Building and Environment, 2004. **39**(10): p. 1253-1261.
[20]Yu, J., et al., *Evaluation on energy and thermal performance for residential envelopes in hot summer and cold winter zone of China.* Applied Energy, 2009. **86**(10): p. 1970-1985.
[21]Šaparauskas, J., E.K. Zavadskas, and Z. Turskis, *Evaluation of alternative building designes according to the three criteria of optimality.* 2010.
[22]Bouchlaghem, N., *Optimising the design of building envelopes for thermal performance.* Automation in Construction, 2000. **10**(1): p. 101-112.
[23]Perini, K. and P. Rosasco, *Cost–benefit analysis for green façades and living wall systems.* Building and Environment, 2013. **70**: p. 110-121.
[24]Yun, G.Y., M. McEvoy, and K. Steemers, *Design and overall energy performance of a ventilated photovoltaic façade.* Solar Energy, 2007. **81**(3): p. 383-394.
[25]Su, X. and X. Zhang, *Environmental performance optimization of window–wall ratio for different window type in hot summer and cold winter zone in China based on life cycle assessment.* Energy and buildings, 2010. **42**(2): p. 198-202.
[26]Waltenbereger, L., *Life Cycle Costs and Life Cycle Assessment of Facade-systems for Industrial Buildings*. 2011, Vienna University of Technology.
[27]Hauglustaine, J.-M. and S. Azar. *Interactive tool aiding to optimise the building envelope during the sketch design*. in *Proceedings of the Seventh International IBPSA Conference (BS2001), Rio de Janeiro, Brazil*. 2001.

[28]Viñolas, B., *Applications and advances of MIVES methodology in multi-criteria assessments*. 2011, Polytechnic University of Catalonia
[29]Lombera, J.T.S.J. and A. Josa, *Planteamiento MIVES para la evaluaciónel caso de la EHE.* Cemento Hormigón, 2008(913): p. 28-36.
[30]Lombera, J.-T.S.-J. and I.G. Aprea, *A system approach to the environmental analysis of industrial buildings.* Building and environment, 2010. **45**(3): p. 673-683.
[31]Ormazabal, G., B. Viñolas, and A. Aguado, *Enhancing value in crucial decisions: Line 9 of the Barcelona subway.* Journal of Management in Engineering, 2008. **24**(4): p. 265-272.
[32]Pons, O. and A. de la Fuente, *Integrated sustainability assessment method applied to structural concrete columns.* Construction and Building Materials, 2013. **49**: p. 882-893.
[33]Reyes, J.P., et al., *Health & Safety criteria for determining the sustainable value of construction projects.* Safety science, 2014. **62**: p. 221-232.
[34]Pons, O. and A. Aguado, *Integrated value model for sustainable assessment applied to technologies used to build schools in Catalonia, Spain.* Building and Environment, 2012. **53**: p. 49-58.
[35]Aguado, A., et al., *Sustainability assessment of concrete structures within the Spanish structural concrete code.* Journal of Construction Engineering and Management, 2011. **138**(2): p. 268-276.
[36]del Caño, A., D. Gómez, and M.P. de la Cruz, *Uncertainty analysis in the sustainable design of concrete structures: A probabilistic method.* Construction and Building Materials, 2012. **37**: p. 865-873.
[37]Ballester, M.V., F.; Yepes, *Análisis multivariante para la estimación de la contribución a la sostenibilidad de los forjados reticulares;*, in *ACHE Congress*. 2011.
[38]Hosseini, S.A., A. de la Fuente, and O. Pons, *Multi-criteria decision-making method for assessing the sustainability of post-disaster temporary housing units technologies: A case study in Bam, 2003.* Sustainable Cities and Society, 2016. **20**: p. 38-51.
[39]de la FUENTE, A., et al., *Multi-criteria decision-making model for assessing the sustainability index of wind-turbine support systems: application to a new precast concrete alternative.* Journal of Civil Engineering and Management, 2016: p. 1-10.
[40]de la Fuente, A., et al., *Multi-Criteria Decision Making in the sustainability assessment of sewerage pipe systems.* Journal of Cleaner Production, 2016. **112**: p. 4762-4770.
[41]Jato-Espino, D., et al., *A fuzzy stochastic multi-criteria model for the selection of urban pervious pavements.* Expert Systems with Applications, 2014. **41**(15): p. 6807-6817.
[42]del Caño, A., et al., *Conceptual Framework for an Integrated Method to Optimize Sustainability of Engineering Systems.* Energy and Power Engineering, 2015. **9**: p. 608-615.
[43]Barros, J.J.C., et al., *Assessing the global sustainability of different electricity generation systems.* Energy, 2015. **89**: p. 473-489.
[44]Hosseini, S.A., A. de la Fuente, and O. Pons, *Multicriteria Decision-Making Method for Sustainable Site Location of Post-Disaster Temporary Housing in Urban Areas.* Journal of Construction Engineering and Management, 2016: p. 04016036.
[45]Saaty, T.L., *How to make a decision: the analytic hierarchy process.* European journal of operational research, 1990. **48**(1): p. 9-26.
[46].Alarcon, B., et al., *A value function for assessing sustainability: application to industrial buildings.* Sustainability, 2010. **3**(1): p. 35-50.
[47].Charleson, A., *Non-structural elements: Those likely to cause structural damage.* Seismic design for architects: Outwitting the quake, 2008: p. 157-171.
[48].Poluraju, P. and G.A. Rao, *BEHAVIOUR OF 3D-PANELS FOR STRUCTURAL APPLICATIONS UNDER GENERAL LOADING: A STATE-OF-THE-ART.* International Journal of Research in Engineering and Technology, 2014. **3**(16): p. 173-181.
[49].Sarcia, S.R., *Design and analysis of a concrete modular housing system constructed with 3D panels*. 2004, Massachusetts Institute of Technology.
[50].Hammond, G. and C. Jones, *Inventory of carbon & energy Version 2.0 (ICE V2. 0).* Department of Mechanical Engineering, University of Bath, Bath, UK, 2011.
[51].Wuppertal Institute for Climate, E.a.E. *Intensity ofmaterial, fuels, transport services, food.* 2011.
[52].Harris, D., *A quantitative approach to the assessment of the environmental impact of building materials.* Building and Environment, 1999. **34**(6): p. 751-758.